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Research Article

DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF MANUALLY OPERATED TWO ROW TROLLEY TRANSPLANTER FOR BRINJAL

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Abstract: India ranks second in vegetable production. However the average yield of vegetables in India is still lower than that in many Asian countries. Transplanting of plug seedlings is a manual and labour-intensive operation. In peak season due to unavailability of labours, timely transplanting is not possible. Cost of labours being increased day by day and therefore manual transplanting is becoming uneconomical. The designing was done based on morphological parameters, agronomical requirements and ergonomical parameters, for the purpose of seeding four seedlings at a time in two rows. The jaw is main operational part of vegetable transplanter which is fitted at the bottom of hollow delivery tubes (4 numbers) for transplanting. Maximum field efficiency of 86.80 % was obtained for seedlings of 4 weeks age on bare bed. In general effective field capacity was found as 0.014 ha/h for 6 weeks age of seedlings on mulch bed. Minimum cost of operation, 3719.94 ₹/ha for seedlings of 6 weeks age on mulch bed. The cost of transplanting 1000 seedlings with designed transplanter came out as ₹ 114.43 as against ₹ 156.38 with manual transplanting. The payback period comes out as 3.71 yeas using 250 hours in a year.

Keywords: Vegetable transplanter, Age of seedlings, Types of bed, Cost of operation, Field efficiency

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Introduction

Agriculture is the backbone of Indian economy. Today, India ranks second worldwide in farm output. About 175 types of vegetables are grown in India, produce 14 % (146.55 million tons) of world's vegetables and have 15 % (8.5 million hectares) of world's area under vegetables. Productivity of vegetables in India (17.3 t/ha) is less than the world average productivity (18.8 t/ha) in 2013-2014. Seeds of the crops like cowpea, okra, carrot *etc.* are either drilled or planted directly. However, most of the vegetable crops like tomato, onion, chilli, brinjal, cauliflower, cabbage *etc.* are transplanted. Transplanting is practice which involves the placing of seedlings either on the ridge or well prepared seedbed, such that they starts establishing their roots and survive as a separate plant. Seedlings for transplanting purposes are raised on beds in which seeds are broadcasted or dibbled in lines. According to the requirement of the procedure followed for transplanting of a particular crop or method. Seedling are then uprooted manually when they are about 4-10 weeks old and transplanted in fields [5] Transplanting of seedling is a manual and labour-intensive operation. Timely transplanting of vegetable crops is essential for higher yields. A survey conducted to access mechanization gaps in the seeding, planting and transplanting of vegetable crops indicated that Indian vegetable growers expressed desire for a low cost vegetable transplanter [4]. The average vegetable growers in India mainly belong to small and medium category of farmers. These farmers need a vegetable transplanter that is simple in design, affordable and suitable for their farming conditions. Considering the small and fragmented holdings under vegetable crops and to avoid bending posture in manual transplanting, it was considered that manually operated vegetable transplanter will be suitable for adoption in Indian conditions.

Material and methods

Determination of Agronomic Requirement for Transplanting Vegetable Seedlings: The agronomic requirement for a particular crop includes time of transplanting, spacing and preparation of bed required for transplanting of that crop *etc.*

The field was prepared until the soil tilth was fine. Then beds were formed using bed former. The recommended dimensions of seed bed were 90 cm top width, 120 cm bottom width and average height was about 20 cm as given by agronomy department.

Table-1 Transplanting time and spacing required for brinjal

SN	Crop	Time of transplanting	Spacing (cm × cm)
1	Brinjal	February July-August October-November	60 × 45

Determination of the Morphological Parameters of Seedlings

The easy passage of plug seedlings through seedling delivery tubes without getting stuck and its subsequent vertical placement along with the movement from the jaw is influenced by the physical properties seedlings such as canopy diameter, plant height *etc.*

Plant height

The seedlings were gently pulled from the plug tray and length of the plant (tip of the leaf to the end of stem *i.e.*, excluding roots) was measured by scale. Ten such observations were recorded for every age (*i.e.*, 4, 5 and 6 weeks of seedlings).

Canopy of plant

Canopy can be defined as the extent to which the vegetation is spread out in horizontal direction for a plant. Randomly selected ten plants were used to measure canopy of plant for each case by means of vernier callipers having least count of 0.01 mm. The spread out is of great importance as the dimensions of the delivery tubes are to be decided on these value.

Design of Manually Operated Two Row Trolley Transplanter

The design criterions for the functional components were kept as lowest, simple design and highly ergonomical in nature.

The conceptual design of transplanter is shown in [Fig-1] with its different functional components. The main components of the designed transplanter are as Main frame, Hollow delivery tube, Jaw, Foot lever, Hand lever, Tray platform and wheels.

Main frame

As the name suggests the main part of the transplanter on which other parts were fixed is the base of the transplanter. The main frame was made up of galvanized iron square pipe size 25 × 25 mm. The height of main frame is kept such that a general male can work without unnecessary str*etc*hing or bending for operating the controls and that to with ease. The main frame is supporting structure to delivery tubes of transplanter. The overall dimension of main frame is 60 cm × 40 cm × 80 cm (L × W × H). The height of main frame was 80 cm for maintaining the height of trolley as 100 cm, to minimize the energy required to push during work. The length of main frame was 60 cm for accommodating seedling tray, decided on the basis of functional grip reach of male operator (*i.e*., 75.07 cm). The width of frame was 40 cm for accommodating seedling trays on the tray platform which was made on main frame.

Hollow delivery tube

The hollow delivery tube was made up of galvanized iron pipe having diameter of 7 cm. The hollow delivery tubes are used to pass the seedlings to the bed. The length of hollow delivery tube was 60 cm and fitted in tube holder. The opening mechanism consisting of two jaws at the bottom of the delivery tube and a hand lever to open these jaws was provided. Tube holder is mounted on the mainframe such that it can be lowered by means of foot lever.

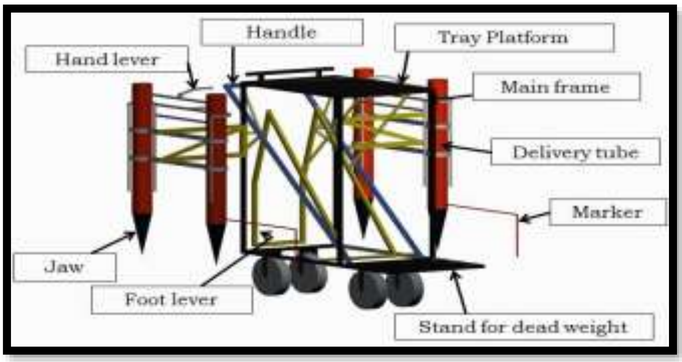

Fig-1 Conceptual design of vegetable transplanter

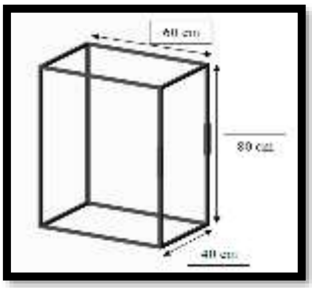

Fig-2 Main frame

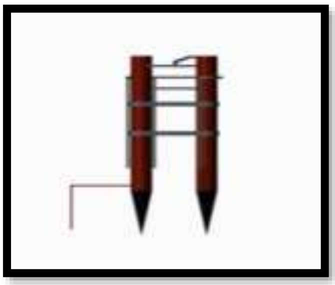

Fig-3 Hollow delivery tube

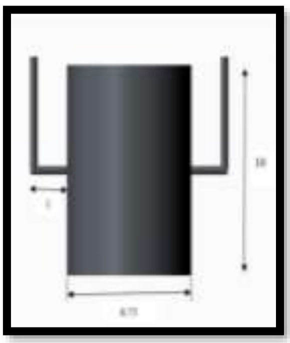

Fig-4(A) Actuator ring

Fig-4(B) A side view actuator ring

At the bottom of the delivery tube a mechanism is provided for allowing seedling to be dropped in the hole punched by the vertical downward movement of the tube into the soil bed. Two slots diagonally opposite to each other were made on the delivery tube. The extended link to operate the actuator ring was taken out from slot. The marker made up of 6 mm stainless steel round bar was fitted on front of hollow delivery tube for marking the position of the next plant.

Actuator ring

Actuator ring was provided inside the hollow delivery tube at the bottom end and connected to hand lever for opening of jaw. The actuator ring was made up of galvanized iron pipe of diameter 6.75 cm and length 10 cm, such that it can move up and down easily inside a delivery tube having 7 cm of diameter. At the middle portion of a ring two numbers of bar (2 cm length, 6 mm diameter) were welded diagonally opposite to each other and both were extended at right angle up to a length of 50 cm which were once again connected to a hand lever for lowering and raising the ring for opening and closing of the jaws. By pressing the hand lever, the actuator ring moves vertically downward and forces the two halves of jaw to move them apart so as to place the seedling in the hole created by the movement of jaw.

Jaw

The Jaw is main operational part of vegetable transplanter which actually penetrates the soil and make space for dropping seedling in the bed. The Jaw was made up using of hollow pipe of galvanized iron. The diameter of pipe was 7 cm, keeping in mind the general height of seedling the height of jaw was kept as 20 cm. The pipe was cut such that when actuator ring was operated by a lever both the jaws (two halves) were separated apart and a path was open for seedling to pass through. The springs are provided around the jaws to bring back the jaws to its original position *i.e*., closed jaws. A spring having 10 mm outer diameter and 40 active coils made out of 1 mm diameter stainless steel wire was used for bringing the jaws back to its original position on relieving the pressure by means of a hand lever.

Levers

Foot lever

As the name suggests it is the lever operated by a foot to lower down the delivery tubes as and when required. The foot lever was fitted on horizontal rod of 40 cm length. The length of foot lever from the horizontal rod was 80 cm fitted at an angle of 560 with horizontal. The inclined foot lever was joined to vertical square pipe of 1.5 cm × 1.5 cm. The height of foot lever 72 cm. The bottom end height of foot lever from ground was 30 cm. The foot lever was made up of galvanized iron square pipe size 1.5 cm × 1.5 cm. The foot lever was fitted with spring and fixed with front end of frame. The spring having 2 mm wire diameter, 15 mm outer diameter and 85 active coils was fitted. The extensions were made up of galvanized iron square pipe size 1.5 cm × 1.5 cm. The length of extension from main frame was 35 cm. The holes of 14 mm were made on extensions at 5 cm gap for fitting of delivery tube. The support of 6 mm thick flat bar was provided between these two extension. The length of support was 30 cm.

Hand lever

The function of the hand lever is to open jaw in the soil bed. Readily available grip was used. Both the right as well as left side levers were located in between two delivery tubes and that too within easy reach of an operator. Since the movement of delivery tube was to be made relative to the frame a set of levers were provided on both the sides. In a set, one lever was fixed and other was operative. The size of fixed lever was 10 cm and other was 13 cm, both were made out of galvanized iron square pipe of 1.5 cm × 1.5 cm. The levers were spaced apart to provide movement of 8 cm. The mechanism was attached to the delivery tube such that it allows the movement of actuator ring inside the delivery tube through appropriate linkage.

Tray platform

In general, the plug tray used for the vegetable crop like brinjal available in the market is of 50 cells having dimensions as 520 mm × 280 mm.

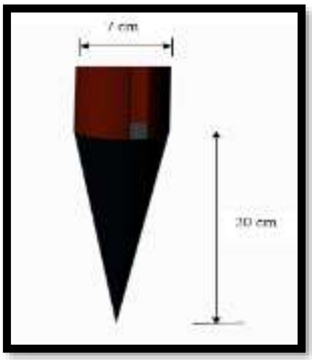

Fig-5 Jaw

Fig-6 Hand lever

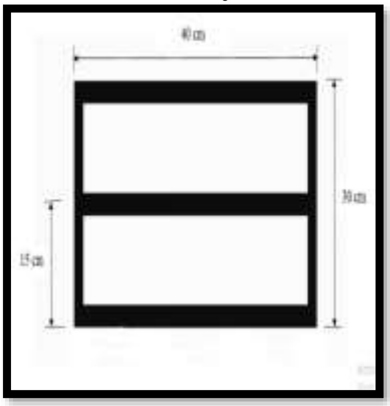

Fig-7 Dead weight stand

So as accommodate the tray, the platform for same was kept as 500 mm × 400 mm (L × W). The platform for carrying seedling trays was made of MS sheet (3 mm thick). It was welded on the main frame.

Dead weight stand

The stand was made to put some dead weight on front side of frame, for avoiding lifting of machine during operation specially while pressing foot lever. The stand was made up of galvanized iron square pipe 1.5 cm × 1.5 cm. The length of folding stand was 30 cm and width were similar to main frame (*i.e.*, 40 cm) of machine. The galvanized iron square pipe was welded at 15 cm interval length wise.

Handle

C shaped handle was made using two galvanized iron square pipes 1.5 cm × 1.5 cm of 105 cm length and one pipe of length 30 cm. They were joined by means of welding. Now the open end of handle was welded on front side of the bottom of the frame. The welding was made such that the closed end was near to rear end of the top of the frame. So as to avoid the lifting of machine from the rear side, a handle was provided such that the force applied at from the rear side acts somewhere near front wheels and whole of the transplanter moves ahead by application of force on that handle.

Wheels

The four rubber wheels were provided for ease of transport in field having 20 cm diameter and 5 cm thickness. The wheels were fitted with clamp and welded to the main frame. The height of clamp was 15 cm and width of clamp was 7 cm. The clamp was made up of 6 mm thick flat bar.

Field Performance Evaluation

To evaluate the machine for its performance, it was tested rigorously in the actual field condition. The developed vegetable transplanter was evaluated in terms of field capacity, field efficiency, labour requirement, cost of operation and other performance parameters such as upright plants, laying down plants and plant mortality.

Upright plants (%)

Planting angle is the angle of inclination of the plant with the vertical. The plants having planting angles of 00 to 300 were considered as likely to produce upright plants [2]. Planting angle was measured for twenty seedlings in each replication.

Laying down plants (%)

Plants standing at less than 300 with the horizontal plane were considered as laying down plants. Laying down plants out of twenty seedlings were noted in each replication and the percentages of laying down plants were calculated.

Plant mortality (%)

Number of seedlings transplanted and survived after 20 days of transplanting in five-meter row length were noted for four different replication in experimental plot and percentage plant mortality was calculated.

Field capacity and field efficiency

Measuring the width of coverage, speed and actual time of operation, theoretical field capacity, effective field capacity and field efficiency were calculated.

Cost economics

The total hourly cost of operation was determined based on fixed cost and variable costs. It was converted into cost required for transplanting of 1000 seedlings, by dividing it with the number of seedlings transplanted per hour and was expressed in ₹/1000 seedlings. The cost of manual transplanting was also observed and calculated for comparison. Payback usage and payback period were also worked out.

Comparative field performance of developed transplanter

The developed two-row manually operated transplanter was compared with manual method for its economic feasibility and subsequent acceptability by vegetable growers. Field capacity, plant mortality and cost economics for both developed transplanter and manual method of transplanting were calculated.

Statistical analysis

The statistical analysis was carried out according to Factorial Randomized Block (FRBD) Design.

Image-1 Developed vegetable transplanter

Results and Discussion

The morphological parameters like plant height and canopy of seedlings were studied for brinjal seedlings and are given in following [Table-2].

Table-2 Plant height of seedlings

Morphological parameter	Brinjal Seedling		
	Age of seedling, weeks		
	4	5	6
Plant height, mm	57.7 ± 2.98	75.4 ± 3.23	97.9 ± 4.66
Canopy of seedling, mm	30.67 ± 1.22	36.33 ± 0.75	55.13 ± 0.93

Field Performance Evaluation of the Vegetable Transplanter:

The results of the experiments for brinjal seedlings were analyzed according to Factorial Randomized Block (FRBD) Design.

Uprights plants

The percentage of upright plants varied from 75 to 88.75 %. [Table-5] shows that the mean upright plants for all three ages were significant.

Image-2 Working of vegetable transplanter

It also shows that the values of upright plants were higher at the middle age of seedlings *i.e.,* 5 weeks. [Table-5] shows that the mean values of upright plants for two types of bed were non-significant. The interaction between age of seedling and type of bed on upright plants was found non-significant at 5 percent level of significance. The higher value of upright plants (88.75 %) in mulch bed may be due to moisture that is present in mulch bed creates the favourable environment for plants survival.

Laying down plants

The percentage of laying down plants varied from 11.25 to 25 %. [Table-5] shows that the mean laying down plants for all three ages were significant. It also shows that the values of laying down plants were least at the middle age of seedlings *i.e.*, 5 weeks. [Table-5] shows that the mean values of laying down plants for both types of bed were non-significant. It also shows that on mulch bed, laying down plants were least. The interaction between age of seedling and type of bed on laying down plants was found non-significant at 5 percent level. The value of laying down plants (11.25 %) is low in case of 5 weeks age and this is reverse as that in case of upright plants. The reason seems to the availability of moisture for longer duration provides favourable environment for plants survival.

Plant mortality

The percentage of plant mortality varied from 11.25 to 18.75 %. [Table-5] shows that the mean plant mortality for all three ages was significant. It also shows that the value of plant mortality was least at the middle age of seedlings *i.e.*, 5 weeks. [Table-5] shows that the mean plant mortality for two types of bed was significant. It also shows that on mulch bed, plant mortality was least (11.25 %). This was because plastic mulches are used in summer and they reflect heat, causing a reduction in soil temperature. Since plastics are impervious to water, soil water will not evaporate, significantly reducing water loss. Plastic mulch greatly reduces weed competition resulting in a healthier crop on the mulch bed as compared to bare bed.

Theoretical field capacity

The values of theoretical field capacity varied from 0.01441 to 0.01688 ha/h. [Table-5] shows that the mean theoretical field capacity for all three ages was significant. It also shows that the value of theoretical field capacity was higher at the 6 weeks (0.01688 ha/h) age of seedlings. As the age of seedling increases the strength of seedling as well as the bonding of roots and soil is firm, due to which the handling becomes easy and less time consuming. Therefore the theoretical field capacity, were higher in 6 week seedlings as compared to 5 week and 4 week seedlings. [Table-5] shows that the mean theoretical field capacity for both types of bed was significant. It also shows that on mulch bed, theoretical field capacity were higher for all the ages of seedlings. The interaction between age of seedling and type of bed on theoretical field capacity was found non-significant at 5 percent level. It clearly states that as the age increases the value of theoretical field capacity increases in both types of beds.

Effective field capacity

The values of effective field capacity varied from 0.01251 to 0.01425 ha/h. [Table-5] shows that the mean effective field capacity for all three ages was significant. It also shows that the value of effective field capacity was higher at the 6 weeks (0.01425 ha/h) age of seedlings. As the age of seedling increases the strength of seedling as well as the bonding of roots and soil is firm, due to which the handling becomes easy and less time consuming. Therefore the effective field capacity, were higher in 6 week seedlings as compared to 5 week and 4 week seedlings. [Table-5] shows that the mean effective field capacity for both types of bed was significant. It also shows that on mulch bed, effective field capacity were higher for all the ages of seedlings. The interaction between age of seedling and type of bed on effective field capacity was found non-significant at 5 percent level of significance. It clearly states that as the age increases the value of effective field capacity increases in both types of beds.

Field efficiency

The percentage of field efficiency varied from 84.39 to 86.8 %. [Table-5] shows that the mean field efficiency for all three ages was significant. It also shows that the value of field efficiency was higher at the 4 weeks age of seedlings. The field efficiency is inversely proportional to theoretical field capacity; therefore the field efficiency shows decreasing trend with the increase in age. [Table-5] shows that the mean field efficiency for both types of bed was significant. It also shows that on bare bed, field efficiency was higher. The interaction between age of seedling and type of bed on field efficiency was found non-significant at 5 percent level of significance. Field efficiency in both the type of bed has shown reducing trend with increase in age from 4 to 6 weeks.

Labour requirement

The values of labour requirement varied from 70.21 to 80 man-h/ha. [Table-5] shows that the mean labour requirement for all three ages was significant. It also shows that the value of labour requirement was least at the 6 weeks (70.21 man-h/ha) age of seedlings. [Table-5] shows that the mean labour requirement for two types of bed was significant. It also shows that on mulch bed, labour requirement were least. The interaction between age of seedling and type of bed on labour requirement was found non-significant at 5 percent level. As the age of seedling increases the strength of seedling as well as the bonding of roots and soil is firm, due to which the handling becomes easy and less time consuming. Mean values of labour requirement has shown reducing trend with increase in age of seedlings with least values at 6 weeks of age.

Cost of operation

The values of cost of operation varied from 3719.94 to 4238.63 ₹/ha. [Table-5] shows that the mean cost of operation for all three ages was significant. It also shows that the value of cost of operation was least (3719.94 ₹/ha) at the 6 weeks age of seedlings. As the age of seedling increases the strength of seedling as well as the bonding of roots and soil is firm, due to which the handling becomes easy and less time consuming. Cost of operation has shown reducing trend with increase in age of seedling for both types of bed. [Table-5] shows that the mean value of cost of operation for two types of bed was significant. It also shows that on mulch bed cost of operation were least. The reason seems to be moisture retains in case of mulch bed was helpful for easy penetration and opening of jaw into the soil. The interaction between age of seedling and type of bed on cost of operation was found non-significant at 5 percent level of significance.

Observed field parameters

Soil moisture and bulk density were determined on the dry basis at the time of transplanting.

Table-3 Observed field parameters

Field parameters	Brinjal Seedling					
	Age of seedling, weeks					
	4 weeks		5 weeks		6 weeks	
	Mulch bed	Bare bed	Mulch bed	Bare bed	Mulch bed	Bare bed
Moisture content, %	13.83	12.82	14.02	13.33	13.28	12.62
Bulk density, g/cc	1.115	1.123	1.110	1.120	1.122	1.124

Comparative Field Performance

The developed two-row manually operated vegetable transplanter was compared with manual method for its economic feasibility and subsequent acceptability by vegetable growers. Field capacity, plant mortality and cost economics of using the device for the purpose were calculated and are given in [Table-4].

Table-4 Comparative field performance of developed transplanter and manual transplanting for brinjal seedlings

Age of seedling (weeks)	Parameters	Mortality (%)	Effective field capacity (ha/h)	Labour requirement (man-h/ha)	Cost of operation (₹/ha)
4	Mechanically	17.50	0.01263	79.22	4197.24
	Manually	16.25	0.0067	149.18	5594.25
5	Mechanically	13.13	0.01384	72.28	3829.45
	Manually	11.25	0.0068	146.15	5480.63
6	Mechanically	15.63	0.01411	70.88	3755.43
	Manually	13.75	0.0069	144.03	5401.13

The transplanter showed 7.70 percent, 16.71 percent and 13.67 percent higher mortality as compared to manual transplanting for 4, 5 and 6 weeks age of seedlings respectively. Similarly, the percentage of labour saving was observed as 70 percent, 74 percent and 74 percent also the time saving of 59 percent, 70 percent and 72 percent in transplanter as compared to manual transplanting for 4, 5 and 6 week age of seedlings respectively. The cost of operation was found to be higher by 13.97 percent, 16.51 percent and 16.46 percent in case of manual transplanting as compared to developed transplanter for 4, 5 and 6 weeks age of seedlings respectively.

Cost Economics of the Developed Vegetable Transplanter

The cost of transplanting seedling with vegetable transplanter was calculated and compared with the cost of manual transplanting. The total cost of operation was determined based on total fixed cost and variable costs. The total cost of developed transplanter was worked out to be ₹ 18,000. Capacity of transplanting seedlings manually and with vegetable transplanter was found to be 240 seedlings/h and 463 seedlings/h, respectively. The cost of manual transplanting was found to be ₹ 156.38 per 1000 seedlings. The total cost of transplanting 1000 seedlings using the vegetable transplanter was found to be ₹ 114.43. Thus a total saving of ₹41.95 per 1000 seedlings could be achieved for transplanting operation with vegetable transplanter. The payback usage in terms of number of seedlings transplanting was found to be 4,29,082 seedlings. The payback period was found to be 926.74 hours or 3.71 year of operation of the vegetable transplanter, which was 37.07 percent of its total expected life.

Conclusions

The age of seedling showed significant results and type of bed individually and in combination showed non-significant results at 5 percent level considering upright plants, laying down plants and plant mortality as parameters for brinjal seedling. Theoretical field capacity, effective field capacity, field efficiency, labour requirement and cost of operation for age of seedling and type of bed individually showed significant results and in combination showed non-significant results at 5 percent level for brinjal seedling. Maximum upright plants were found as 88.75 percent, minimum laying down plants as 11.25 percent and minimum plant mortality as 11.25 percent with 5 weeks age of seedlings on mulch bed. Maximum theoretical field capacity was found as 0.01688 ha/h, maximum effective field capacity was found as 0.01425 ha/h, minimum labour requirement was found as 70.21 man-h/ha and minimum cost of operation was found as 3719.94 ₹/ha with 6 weeks age of seedlings on mulch bed. Maximum field efficiency was found as 86.80 percent with 4 weeks age of seedlings on bare bed. The saving on transplanting cost by using the developed transplanter when compared with manual transplanting was found to be ₹ 41.95 per 1000 seedling transplanting. The payback period was found to be 926.74 hours or 3.71 year of operation of the vegetable transplanter.

Application of research: The research in the direction will be beneficial in reducing the input cost of rearing vegetable crops and increase the timeliness without damaging the tender seedlings of the crop.

Research Category: Fabrication of designed transplanter

Abbreviations: h = hour, ha = hectare, man-h/ha = man hours per hectare, t/ha= tonne per hectare, FRBD = Factorial Randomized Block Design, *etc.* = *et*cetera.

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Author statement: All authors read, reviewed, agree and approved the final manuscript

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Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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